

Simulation of Earth-Moon-Mars Environments for the Assessment of Organ Doses

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❖ Simulation of Space Radiation Environment

- GCR in interplanetary space^(1,2) represented by GCR deceleration potential, ϕ .
- Trapped protons⁽³⁾ at low Earth orbit (LEO) and the vertical cutoff rigidities for ISS orbit⁽⁴⁾ and geomagnetic transmission factor for GCR at LEO⁽⁵⁾.
- Statistical prediction of solar particle event (SPE) occurrences⁽⁶⁾ and fluences as a function of mission period by a non-homogeneous Poisson process model fitted to a database of proton fluence measurements of SPEs⁽⁷⁾.
- Calculation of Martian atmospheric shielding thickness at elevation for variable solar activities using Mars Global Surveyor data and the distribution of cosine angle.

❖ Assessment of Organ Doses

- Transport properties of the shielding materials and the astronaut's body tissues: NASA BRYNTRN⁽⁸⁾ and HZETRN/QMSFRG code system^(9,10)
- Spherical shield configurations including spacesuit and equipment room of a spacecraft as 0.3 and 5.0 g/cm² aluminum, respectively.
- Body shielding distribution at the sensitive organs of astronaut of computerized anatomical man (CAM) model⁽¹¹⁾
- Acute radiation response and NASA limits analysis with organ dose estimates for mission scenarios^(12,13,14).

ARR Sickness at Severity Level⁽¹²⁾

Severity Level	Upper Gastrointestinal Distress (UG)	Fatigability and Weakness (FW)
1	No effect	No effect
2	Upset stomach, clammy and sweaty, mouth waters	Somewhat tired with mild weakness
3	Nauseated, considerable sweating, swallows frequently to avoid vomiting	Tired with moderate weakness
4	Vomited once or twice, nauseated, and may vomit again	Very tired and weak
5	Vomited several times, including the dry heaves, severe nauseated, and will soon vomit again	Exhausted with almost no strength

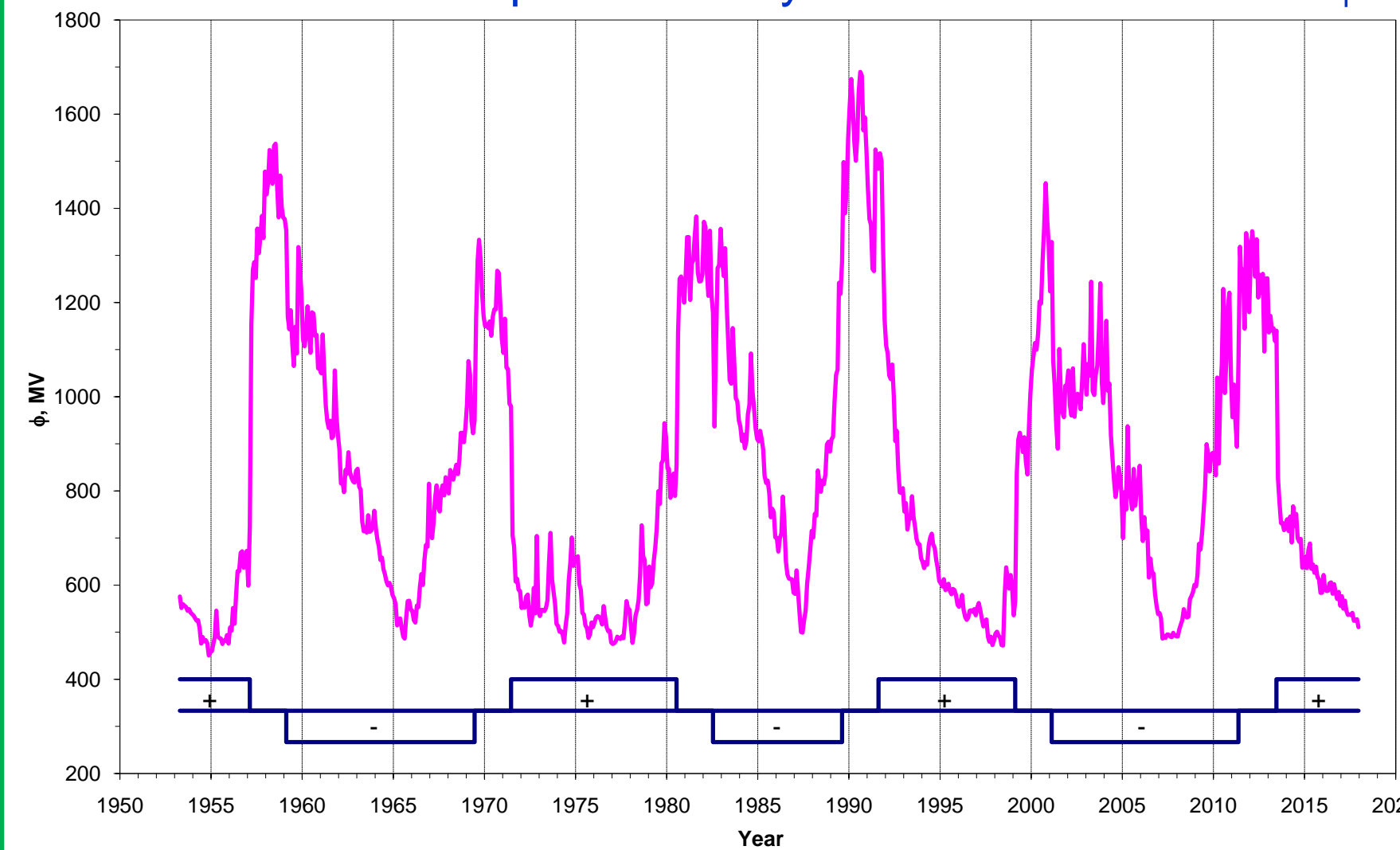
Exposure limit by NASA ⁽¹⁴⁾	Organ dose, Gy-Eq
30-d limit at Skin	1.5
30-d limit at Eye	1.0
30-d limit at BFO	0.25
Minimum BFO dose for ARR	0.5

References

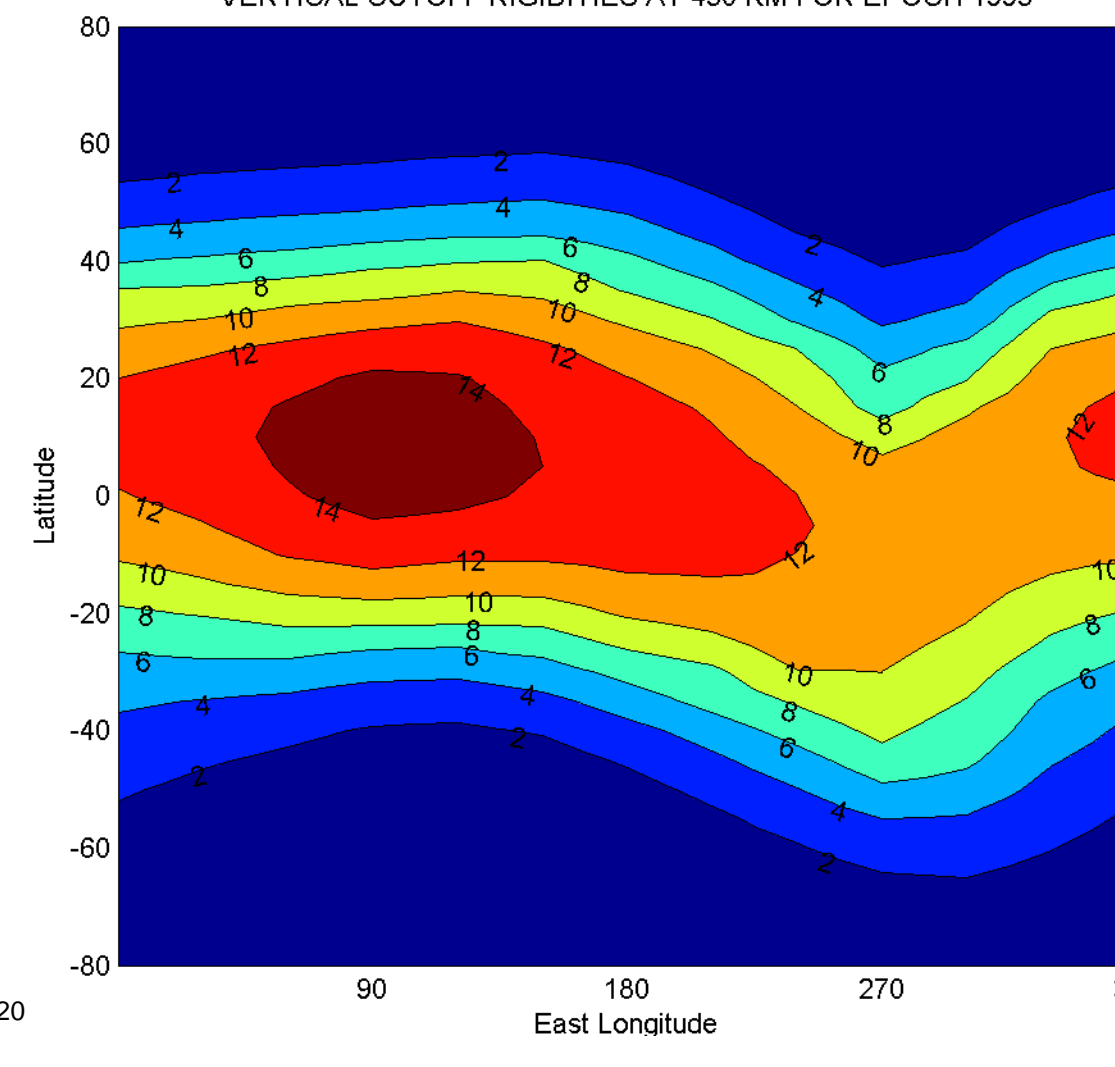
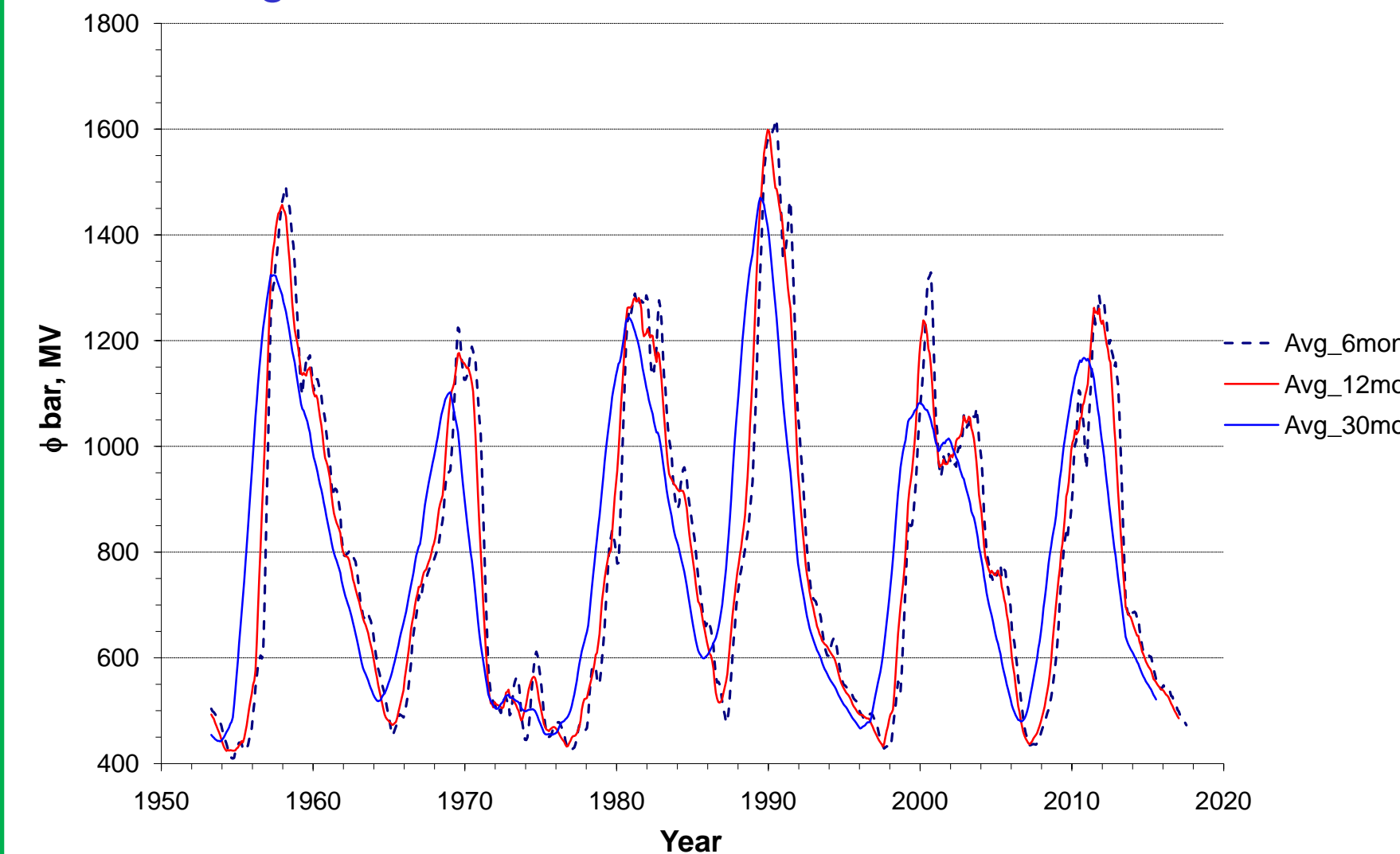
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Environmental Parameters for Space Radiation Simulation

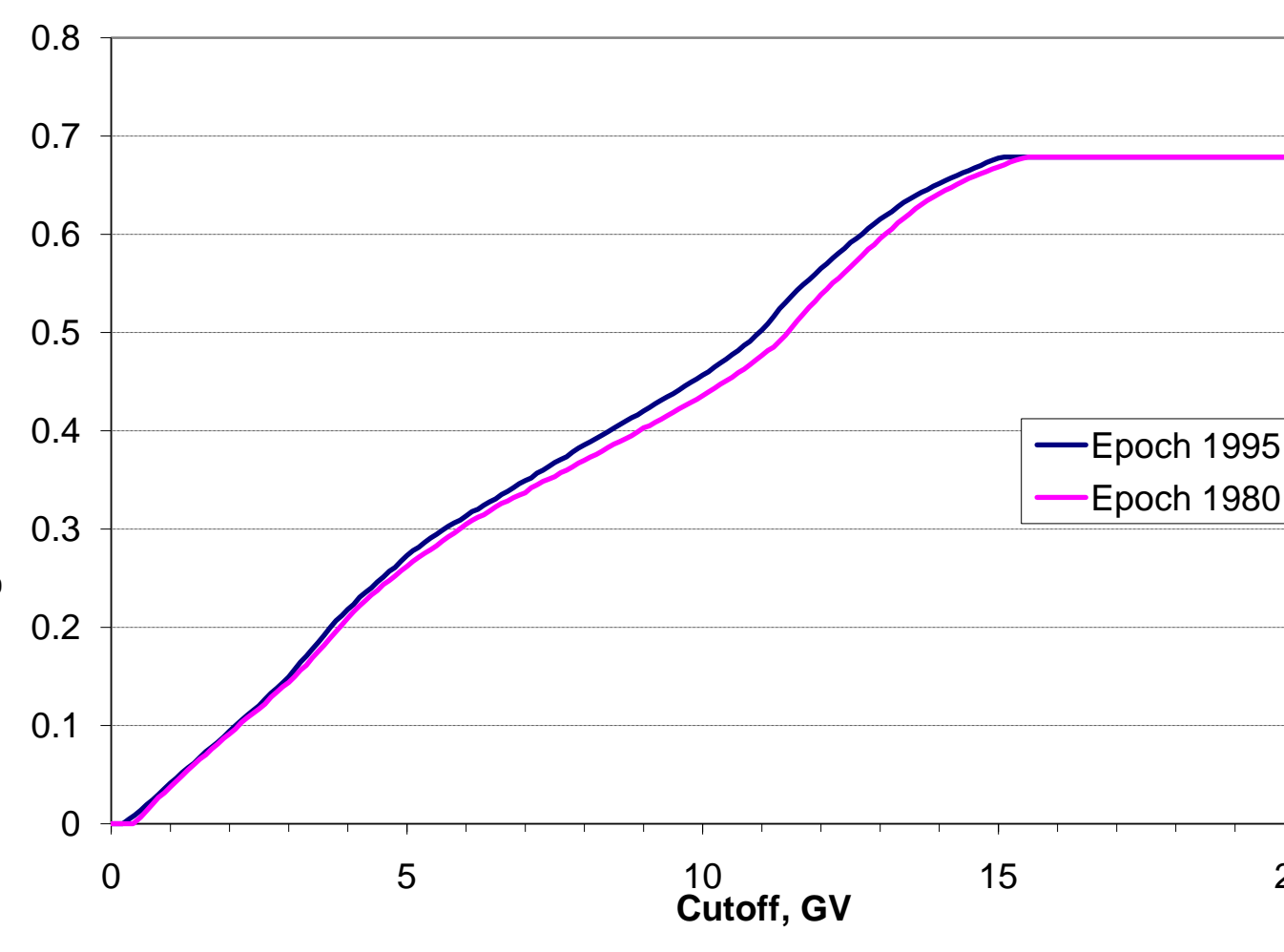
GCR Environment Represented by Deceleration Potential ϕ



Average GCR Environment for a Given Mission Period



Geomagnetic Transmission Factor (51.6 deg X 450 km)



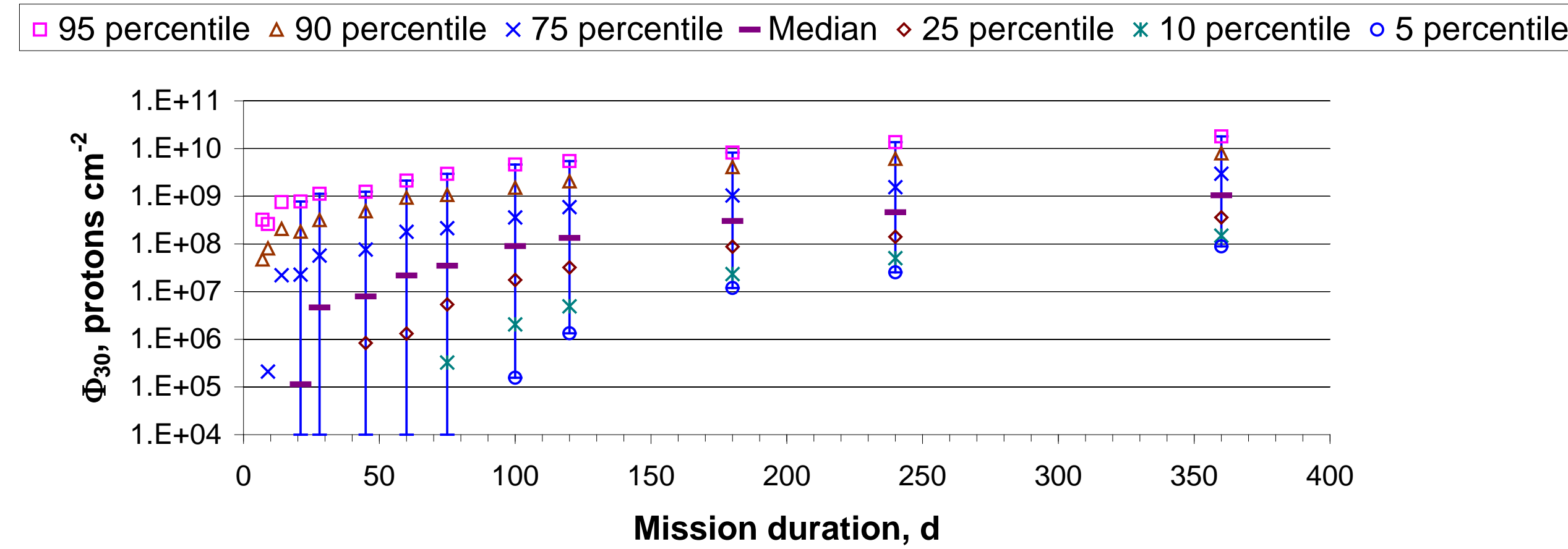
Environmental parameters		Mission duration		
		6-Month	12-Month	30-Month*
GCR deceleration parameter (ϕ), MV	Solar minimum	428	428	428
	Median solar activity	735	743	773
	Solar maximum	1100	1100	1100
SPE fluence (Φ_{30}), p/cm ²	Median level	1.39x10 ⁸	9.74x10 ⁸	5.26x10 ⁹
	August 1972 SPE	8.10x10 ⁹	8.10x10 ⁹	8.10x10 ⁹
	Upper 95% level	1.08x10 ¹⁰	4.80x10 ¹⁰	1.35x10 ¹¹

30-Month	Φ_{30} by each segment			Φ_{30} by fraction to 30-month mission		
Mars	Transits	Mars stay	Total	Transits	Mars stay	Total
Mission	12-month	18-month	30-month	12-month	18-month*	30-month
Median	2.78x10 ⁸	2.03x10 ⁹	2.34x10 ⁹	2.10x10 ⁹	3.16x10 ⁹	5.26x10 ⁹
Upper 95%	2.16x10 ¹⁰	7.50x10 ¹⁰	9.66x10 ¹⁰	5.40x10 ¹⁰	8.10x10 ¹⁰	1.35x10 ¹¹

*Organ dose estimates using SPE fluences proportional to the simulated fluence of 30-month mission.

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Simulated Distribution of SPE Fluence at 30 MeV



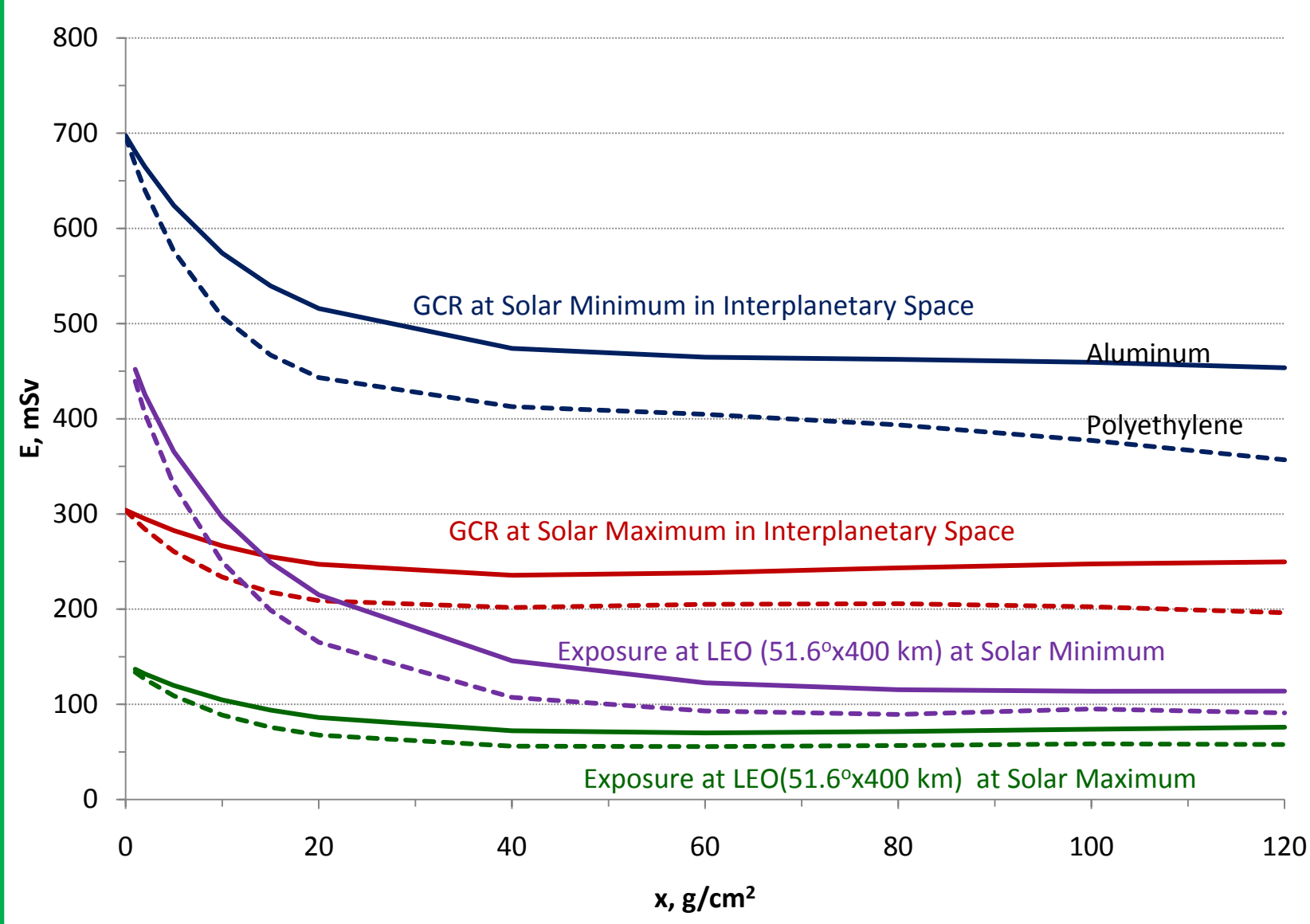
Vertical Distribution of Mars Atmospheric Properties*

Altitude, km	T, °C	p, kPa	ρ , g/cm ³	Atmospheric shielding thickness, g/cm ²	
				Low density model	High density model
8.0	-41.2	0.34	7.64x10 ⁻⁶	0.14	0.19
6.0	-37.0	0.41	8.98x10 ⁻⁶	3.16	4.34
4.0	-35.0	0.49	1.07x10 ⁻⁵	6.73	9.25
2.0	-33.0	0.58	1.27x10 ⁻⁵	10.97	15.08
0.0	-31.0	0.7	1.50x10 ⁻⁵	16.00	22.00
-2.0	-29.0	0.84	1.78x10 ⁻⁵	19.04	26.17
-4.0	-27.0	1.00	2.12x10 ⁻⁵	22.64	31.13
-6.0	-25.0	1.2	2.52x10 ⁻⁵	26.92	37.01
-8.0	-23.0	1.44	2.99x10 ⁻⁵	32.00	44.00

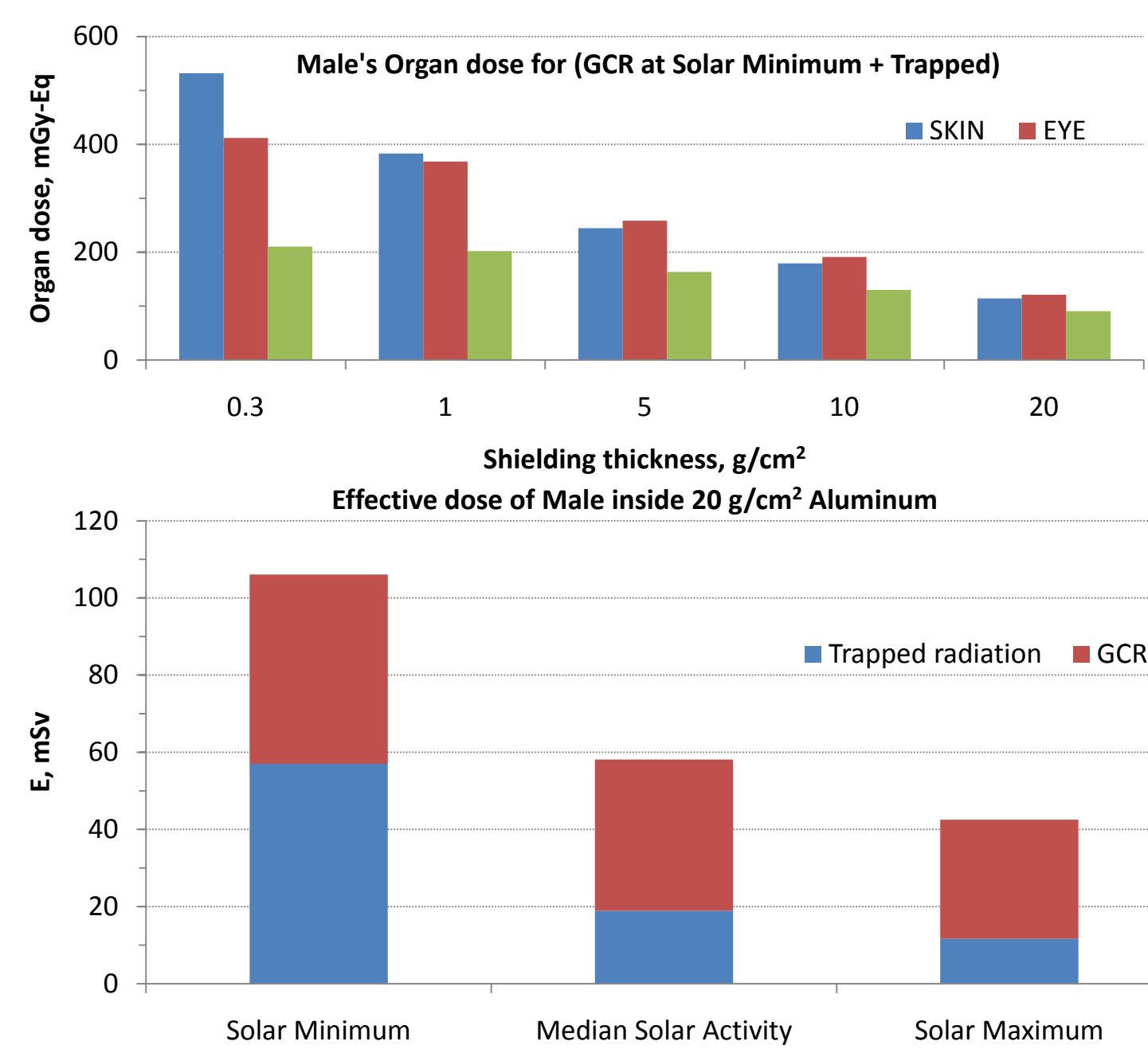
*Temperature and pressure data based on Mars Global Surveyor

Exposure Limit and Acute Radiation Risk Analysis for Mission Scenarios

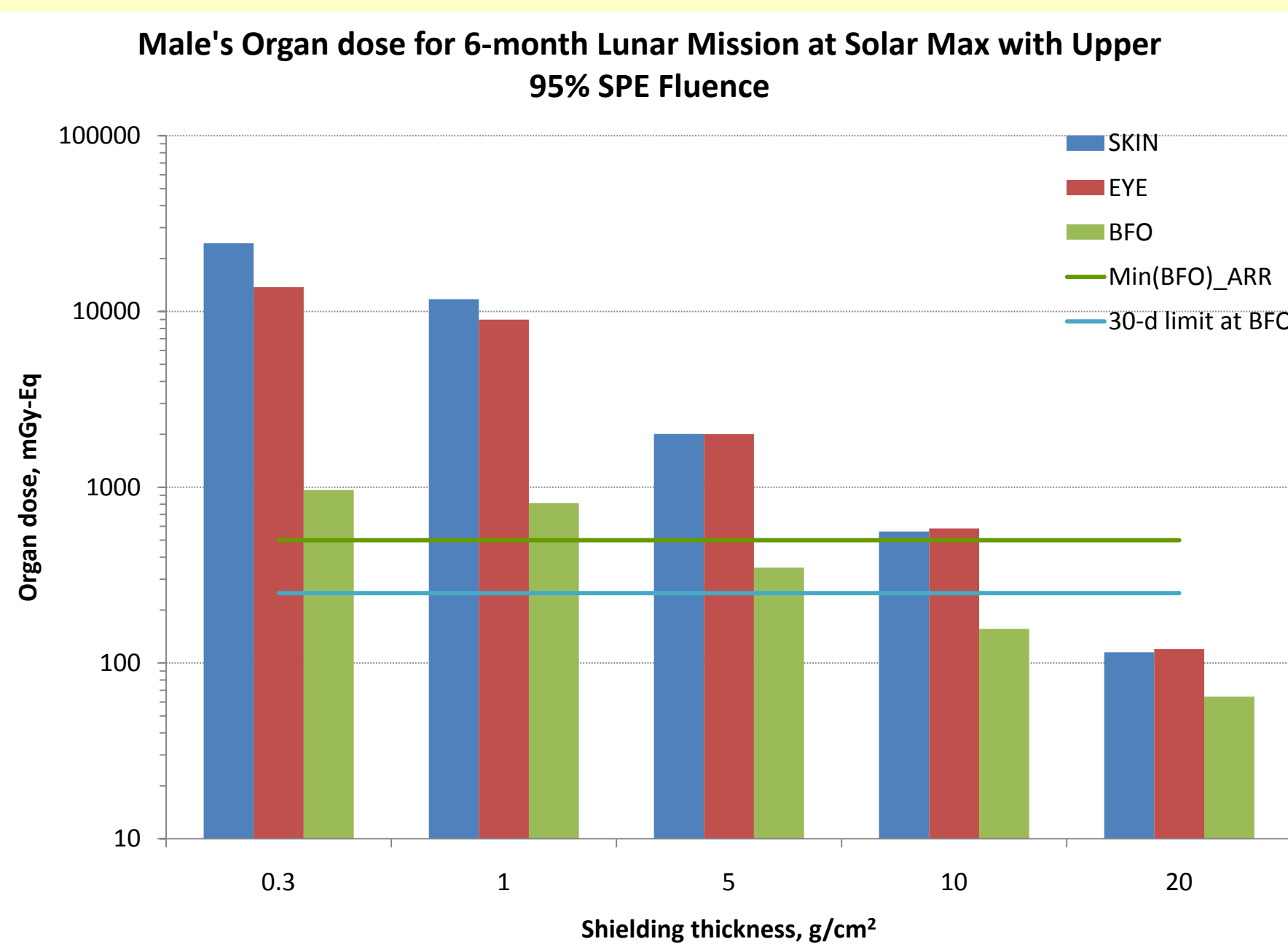
Annual Effective Dose Comparison



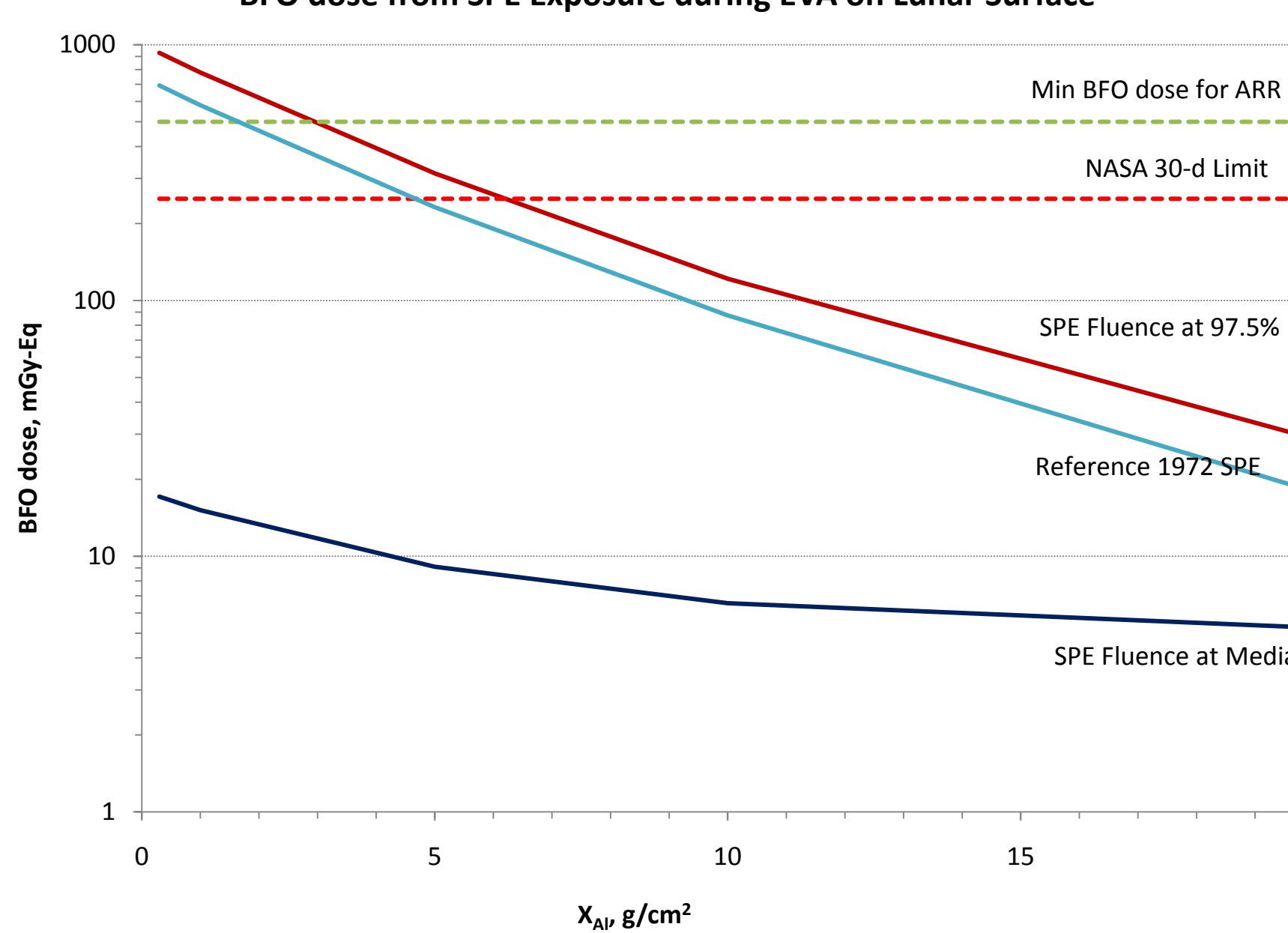
6-month LEO Mission at 51.6°x400 km



6-month Lunar Mission

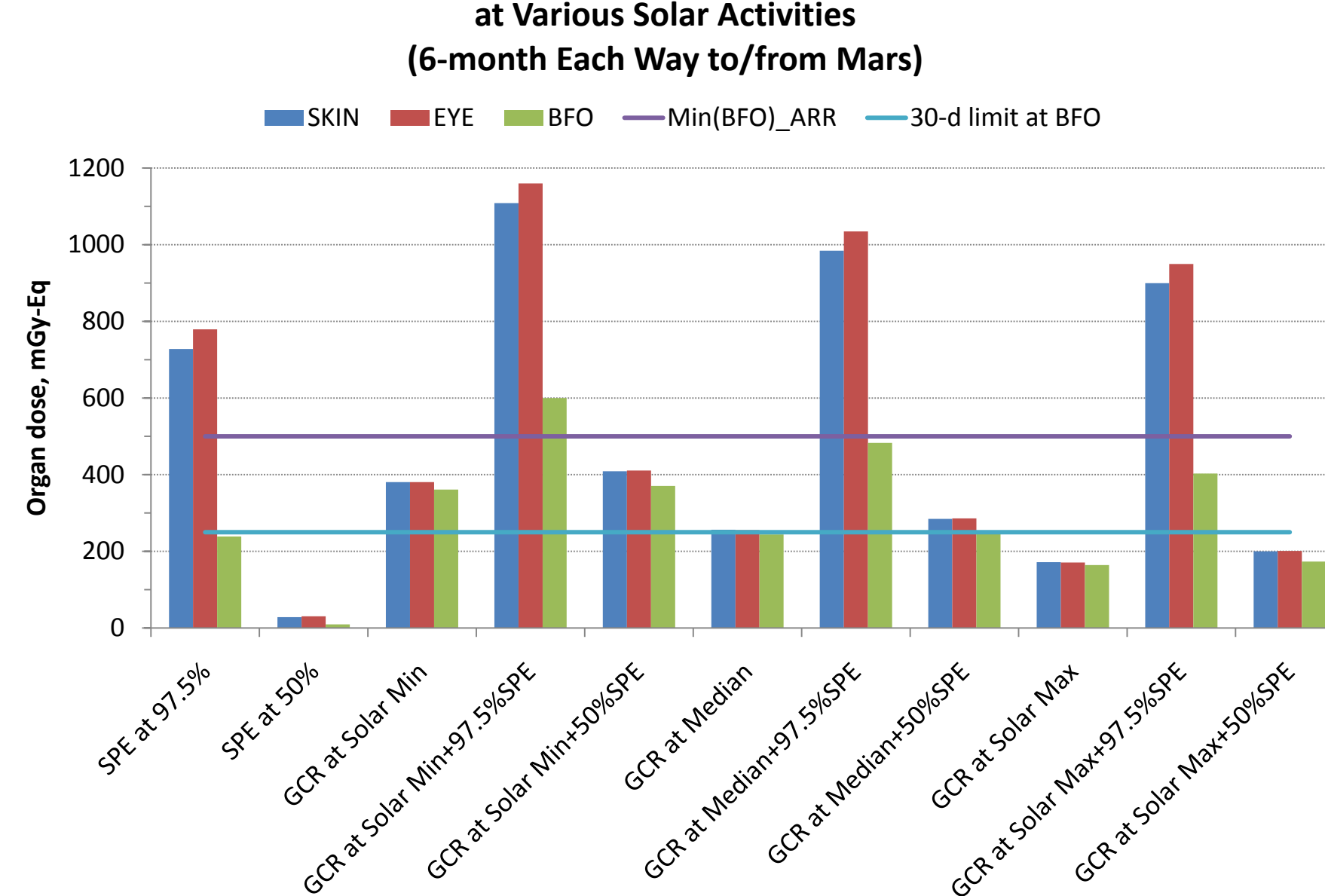


BFO dose from SPE Exposure during EVA on Lunar Surface

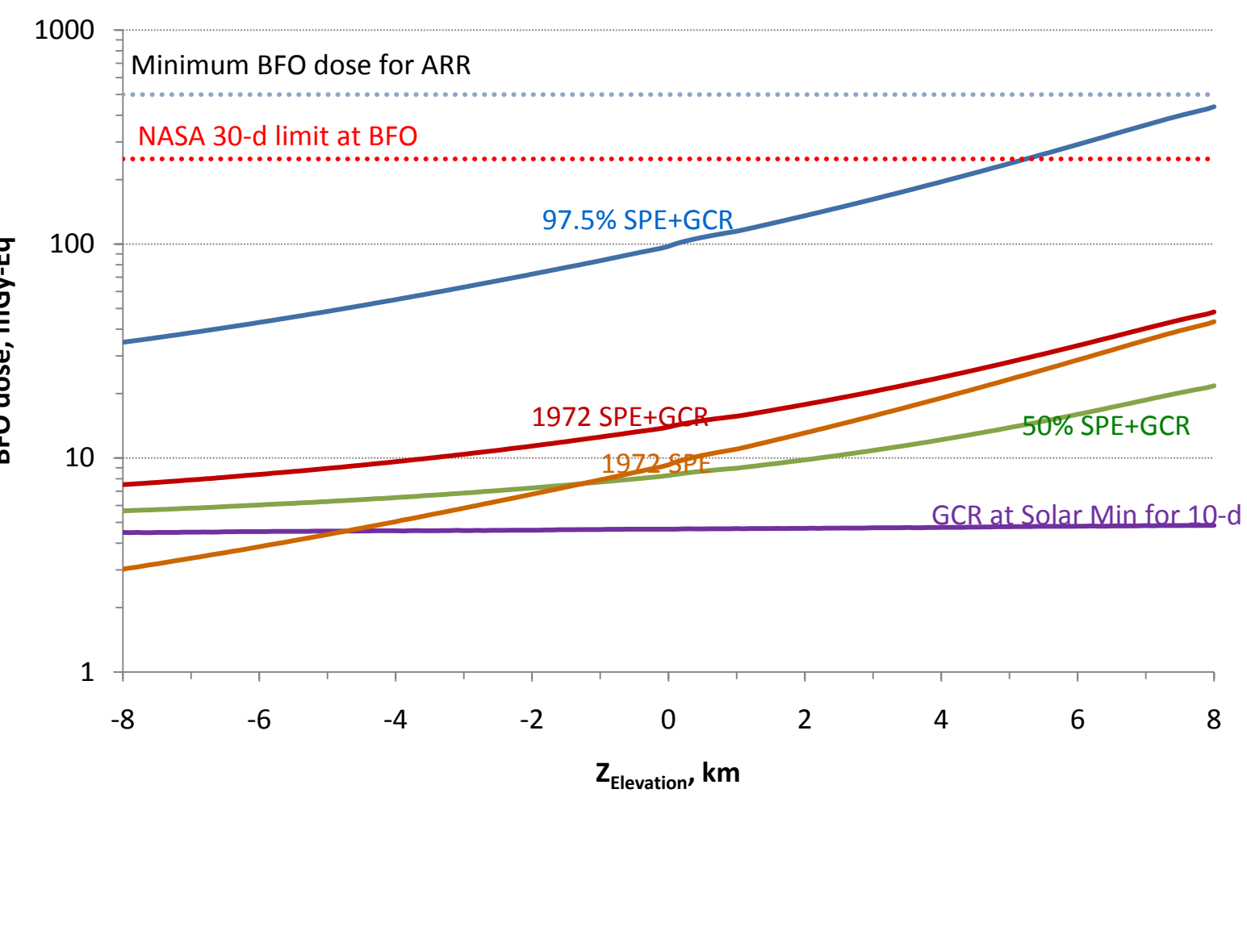


30-month Lunar Mission (6-month transit – 18-month Mars stay – 6-month transit)

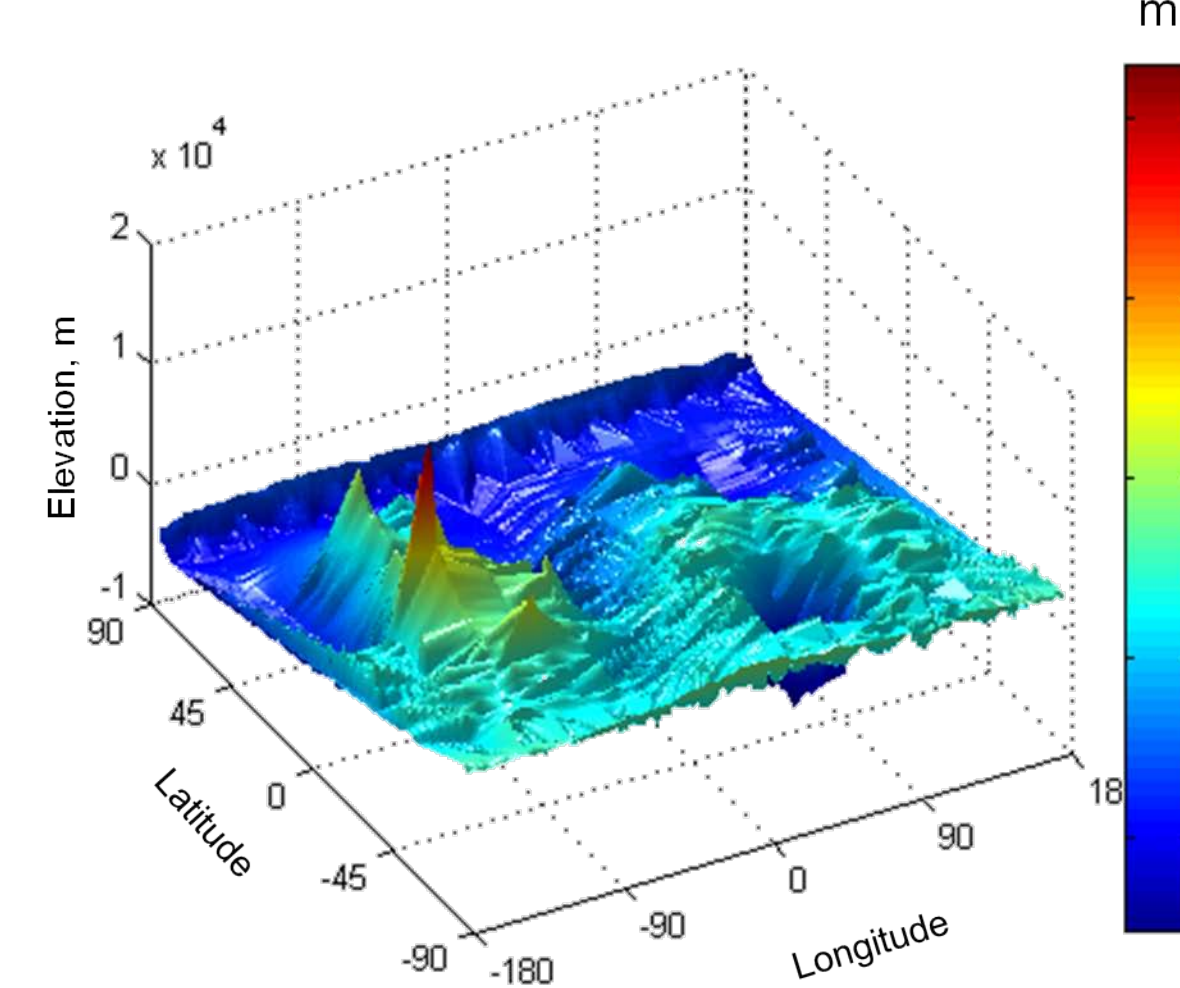
Organ Dose of Males inside 20 g/cm² Aluminum during the Transits at Various Solar Activities (6-month Each Way to/from Mars)



BFO dose of Male during 10-d EVA behind 1 g/cm² Aluminum Shielding at Mars Elevation



Mars Orbiter Laser Altimeter (MOLA) Topography - Mars Global Surveyor -



Effective Dose of Males with 20 g/cm² Al Shielding on Martian Topography

